Status of Instrumentation

(or planned initial deployment for construction projects)

Planned Rings	Profile	Emittance	BPM	Beam Loss	Current	Misc	Tune
SNS Ring	Wire (low intensity) IPM (high intensity) Luminescent[1] (proposed) Harp		Open strip[2]	Ion Chamber[3] Liquid Scintillator[4]	Toroid[5]	e-detecors[6] beam-in-gap[7]	
J-PARC (JKJ) 3GeV Synchrotron	IPM SEM[2]		Diagonal cut ESM[3] Stripline[4]	Ion Chamber Scintillator	Toroids[5] Wall current monitor	e-detectors beam-in-gap (proposed)	
J-PARC (JKJ) 50 GeV MR	gas sheet PM[1] SEM[2]		Diagonal cut ESM[3] Stripline[4]	Ion Chamber Scintillator	Toroids[5] Wall current monitor	e-detectors beam-in-gap (proposed)	
FNAL P Driver	Ionization type, MCP, 64 strips 1mm apart, L=3m[4]		Single plane elliptic electrostatic PU[1]	Ar filled ion chambers[5]	Fast BCT[2] DCT[3]	100kHz - 0.6 GHz wall current monitor fast stiplines - 1m long, 50 Ohm for wide band diagnostics transverse dampers - 1m long	Single plane elliptic electrostatic PU[6]
CERN LHC	wire (lin. low intensity)[5] IPM (all intensities)[3] luminescent[4]	synchroton light[7]	button[8] few strip[9]	Ion Chamber[11] ASEM[10,12]	Toroid	quadrupolar BPM[14]	

Existing Rings:							
CERN Rings:							
BOOSTER, PS	wire rotative[1]		electrodes	ASEM[10]	Toroid	quadrupolar BPM[13]	
transfer l.	SEM grids		electrodes	ASEM[10] ion chambers[11]			
SPS Ring	wire (lin. low int., rot. high int.)[2] IPM (all intensities)[3] luminescent[4]	synchroton light[6]	electrodes	ion chamber[11]	Toroid	e-cloud strip det.	
transfer l.	OTR screens		buttons	Ion chambers[11]			
ISIS Synchrotron	residual gas monitor[1] single wire 'halo' monitor[2] multi wire single turn[3]	emittance determined from profile monitors	single plane split induction electrodes[5]	Argon filed coaxial cables	Toroid[6]	Thermocouples[7] Beam Chopper[8] Beta Kicker[9]	
FNAL Booster	one horizontal and one vertical IPM with turn-by-turn data acquisition	see devices under "Profile" for transverse emittance	4-electrode stripline type pickups (~50)	"Tevatron" style ion chambers in tunnel (~60)	AC toroid with Hereward feedback	"Time-of-Flight" relative energy monitor in 400MeV injection line	Pinger for horizontal tune measurement (vertical pinger temporarily? appropriated for extraction gap creation)
	slow single-wire scanners at injection point	wall current monitor for longitudinal emittance	AM-PM electronics operating at fundamental RF frequency (38-53 Mhz)[1]	Uncalibrated plastic scintillator / phototube devices at selected locations to see fast losses[2]	DCCT	~ 6GHz bandwidth wall current monitor for longitudinal instability diagnostics, mountain range displays, and bunch length detector	

		Multi-wire harp type profile monitors in injection and extraction lines	AM-PM electronics operating at injected bunch frequency (200MHz) on just a few BPM locations	Interlocked rad. detectors (chipmunks) outside tunnel provide useful "average" beam loss information (~50)	Wall current monitor for bunch-by-bunch intensity information	Wall current monitor for low level RF system phase feedback
DESY Rings						
DESYIII	fast[5] wire scanners (up to 220 mA) IPM[1] (first prototype was tested many years ago)		inductive pick-up[7]	Scintillator[8]	Toroid[10]	"stepping wire" (in preparation)[2] 3 resistive wall monitors[13]
PETRAp	fast[5] wire (up to 160mA) IPM[1] (sensitive, correct beam width at small bunch currents only)		capacitive pickup (button) (for e and p)[12]	Long segmented Ion Chamber (planed)	Toroid[9,10,11]	"stepping wire" (in preparation)[2] 2 resistive wall monitors[13]
HERAp	OTR Screen (proposed, for injection[6]) IPM[1] (sensitive, correct beam width at small bunch currents only) fast[5] wire (up to 160mA)		Directional coupler Pickup (Stripline)[12]	PIN diode BLMs (counting mode)[3]	Toroid[9,10,11]	BLMs at scrapers[2,4] "stepping wire" (in preparation)[2] fast wall current pick-up for bunch length measurement
LANSCE Ring	None in ring[8]	rms from profiles of extracted beam	Stripline w/ 50 ohm termination[6] Capacitive[7]	Ion Chamber[1] Liquid Scintillator[2] Vacuum photo diode[3]	Toroid[9] Wall current	e-detectors[11] Pinger e -sweeper

GSI Synchrotron	IPM[1] HARP[2]	IPM[1] transverse Schottky[3]	capacitive pick up[4]	plastic scintillator[5]	Toroid AC [6] Toroid DC[7]	longitudinal Schottky[8], capacitive pickup[9] tomography[10]	Tune: exciter + pickup (BTF)[11], transverse Schottky
IPNS							
IPNS Ring	IPM[1] (horiz.), RWM[2] (long.), CT[3] (long.)		PIE[4] electrodes	PMT/scintillators, CT	CT	RFA (electrons)	PIE electrodes
PTS Transfer Line	SSEMs[5], SWIC/PAS[6]	SSEMs, SWIC/PAS	SSEMs, SWIC	ICs[7]	CTs[8]		
BNL Rings							
RHIC	Transverse: IPM, Luminesence Longitudinal: WCM	Transverse: Schottky, Luminesence Longitudinal WCM, Schottky	shorted stripline, 25 cm long, single + dual phase	ion chambers (TeV Style)	DCCT, WCM	Buttons	coherent:Kicked tune, incoherent: Schotttky+ PLL
AGS							

Additional Notes:

<u>*SNS :*</u>

248m storage ring
< 1.3 GeV P
up to 1.44x 10^{14} ppp (1 msec storage)

1) gas ionization system
2) Dual plane, 4 stripline design. position + relative phase , 65M samples/sec
3) Volume detector (N) (~ 10 kHz,)
4) Photo multiplier, > 1 MHz response, MPS input.
5) Fast current transformer, 15 mA - 100 A
6) Related to e-P instability - need 100 MHz response
7) To measure residual beam in the extraction gap, < 1.e-4 of nominal beam intensity

J-PARC (JKJ)

1) Under R&D for high intensity beam.
2) Using metalized thin films for high intensity is under R&D. Planned to install in inj. / ext. beam transport lines.

3) For COD measurement / single pass
4) Fast response.
5) Wideband frequency is covered by several toroids.

FNAL P driver — 16 GeV Synchrotron
1) 100 mm length, Turn-by-turn measurements, ± 1.0 mm
2) 1.5 kHz-20 MHz, 5 V/A, 245 mm ID, Turn-by-turn measurements, 0.1% error
3) 245 mm ID, Resolution 10 mA, 500 Hz drift 5mA/24 h
4) turn-by-turn time resolution
5) V=0.11 cc, Time resolution 0.1 ms
6) , 100 mm length FEE, Resolution of 0.01 tune units,kick of a few tenths of a mm

LHC / CERN Rings:
1) 20 m/s
2) 0.6 and 6 m/s
3) e-detection, commisioning phase, intensity dependence observed in the SPS
4) commisioning phase, backgrond problem in the SPS
5) total allowed beam intensity 1 E13, in last weeks lower threshold observed in the SPS, under investigation
6) light from the edge of a bending magnet
7) light from a undulator at 450 GeV and at 7 TeV from a the edge of a bending magnet
8) mounted on the quad mag, cold
9) near IP and some special
10) Aluminium Cathode Electron Multiplier
11) 1 liter N2 at 1 atmosphere
12) few units for the observation of fast losses
13) radial magnetic field detection, no common mode sigbal, bunch lendth 200 ns
14) strip line

ISIS Ring — 163m, 70-0800 MeV RCS, 50 Hz. $2x10^{13}$ ppp, Harmonic 2 RF System
1) Single detector stepped over beam width.
2) halo position determined by measured beam loss on adjacent BLM.
3) used for 1st turn orbit setup with a beam stop.
4) Scintilators used for single turn injection and extraction beam diagnostics
5) 200 MHz bandwidth, switching gain devices for use with high intensity and chopped beams. Used for transverse measurements and summed for longitudinal measurements
6) Resolution range $1x10^{10}$ to $4x10^{13}$ protons
7) Thermocouples placed on dipole vacuum chambers downstream of beam collector systems to prevent dipole damage
8) electrostatic chopper in jection line controls injection pulse length from <1 turn to full intensity (160 turns)
9) Fast h and v kicker magnets (rise time ~ 1us , duration ~ 0.5 ms) perturbs orbit for transverse lattice measurements.

FNAL Booster Ring: multi-turn H- charge exchange injection at 400MeV with 200MHz bunch structure, typically 12 turns
200MHz structure washes out in few turns, then beam is semi-adibatically captured in Booster harmonic 84 buckets (38 MHZ at 400MeV)
accelerate to 8 GeV in 33 millisec (15 Hz resonant magnet circuit)
RF harmonic = 84; frequency 38-53 Mhz
typical injected intensity 5E11 to 7.5E12
typical high intensity injection-to-extraction efficiency 70%
1) blind from injection until RF capture (~25-30 turns)
2)sub-microsecond timescale

DESY :
1) gas ionization monitor system
2) For tail measurements
3) 10 MHz response, counting mode
4) PMTs and PIN diodes
5) up to 1 m/s, upgrade planed
6) for max. 10 bunches only, to measure the quadrupole moment
7) 30 kHz-250 MHz Bandwidth
8) Photomultiplier, > 10 MHz response.
9) DCCT slow current transformer typ PCT or M-PCT, 0-200 mA, res: 0.5 μA, CD - 100kHz
10) AC Fast current transformer, 30 kHz - 20 MHz, Cal: 10^{11} p/V, res: <<10μA, meas. precise transport efficiency
11) difference of 9) and 10) = coasting beam
12) Broadband readout (<96 ns)
13) for bunch length, timing and feedback; 2 MHz - 1 GHz bandwidth

LANSCE Ring:
1) Nitrogen at 1 std. atm. Same type of ion chambers also used in personnel protection system.
2) Used for fast, ns time scales. Saturates on PSR extraction losses.
3) Fast, but less sensitive, so does not saturate on PSR extraction losses.
4) Slit and collector method used up to 100 MeV.
5) Used at 800 MeV.
6) Primary BPM system for ring, but only works well for injected beam with 201 MHz structure.
7) Only have a couple of these in the ring.
8) No profile measurements in ring, but measure profile immediately after extraction. Can deduce ring profile at any time by extracting early.
9) Have both fast and slow toroids.
10) Used after each DTL tank.
11) ANL-style, with LANL-developed high-bandwidth electronics at detector

12) Also use ion chambers for personnel protection (separate electronics from loss monitors)

GSI

Synchrotron - all ions, space charge limit < 10^{12}, ions (charge dependent) up to 12 GeV/u, fast and slow extraction, electron cooling possible, 218 m circumference
1) MCP + wire array readouut, ion deflection (new development: B field and electron detection, MCP + phosphor + CCD)
2) First turn diagnostic
3) for debunched beam, capacitive pick up plates
4)show box type, high impedance pre-amp, 100 MHz bandwdth
5) counting mode, max. rate ~ 5 MHz
6) for injection, 1 Mhzbandwidth passive transformer, 0.1 microA resolution
7) DC bandwidth, 50 kHz, 1 microA resolution
8) for momentum spread of DC beam
9) bunch shape observation bandwidth 100 MHz (high impedance) bandwidth 1 GHz (50 Ohm)
10) phase shape reconstruction using capacitive pickup
11) frequency sweep or while noise excitation

IPNS Ring

450 MeV RCS, 30 Hz
1) Position and Profile System (PAPS)--only weak magnetic field (3-4 G, ave.) present; residual from combined-function magnets (full power, 5 kHz)
2) Resistive Wall Monitor (full power, wide-band)
3) Pearson Coils (full power, <20 MHz)
4) split-can pair, horizontal and vertical (full power, < 50 MHz)
5) Segmented Secondary Emission Monitors (full bunch, low power)
6) Segmented Wire Ionization Chamber, Au-coated, W wire, 2 mil (0.03 mil Au) / Position And Size monitor (package 2 m in front of target, full power)
7) Ionization chambers
8) Pearson coils and Bergoz MPCT (full power, reduced BW)

Status of Instrumentation
(or planned initial deployment for construction projects)

Planned Linacs	**Profile**	**Emittance**	**BPM**	**Beam Loss**	**Current**	**Mean Energy and Phase**	**Energy / phase Spread**	**Misc**
SNS Linac	Wire (low energy) Laser wire[1] (Superconducting region)	Slit & Collector[2] Beam Shape Monitor[3]	Shorted strip, RF IQ receiver[4]	Ion Chamber5 Liquid Scintillator[6] Neutron detector	Toroid[7]	phase from BPMs		
RIA	Wire	Low energy: Slit/Collector medium & high energy: wire/rms[4]	Shorted strip	Neutron detectors and medium and high energies	All energies: BCM, low and medium energies - Faraday cup	Phase:Resonant Pickup[1] at low and medium energy, Shorted strip everywhere Energy:all energies-TOF, at low energy SBD/GasProp.[3]	Bunch shape: all energies: wire/sec electron[2] at low energy SBD/GasProp.[3]	
FNAL P Driver	Moveable single plane grids (48 wires, 0.5-1.0-1.5 mm spacing)[1] slow single wire scanners Ioniz. Type MCP Ampl., 48 strips 1.5 mm apart[1]		Single plane stripline, 0.5 mm resolution[1]	Argon Ion chambers[1]	BCT			
J-PARC (JKJ)	Wire Scanner	Slit & Collector[2]	Stripline[1]	Ion Chamber[3]	Toroids(slow)[4] Toroids(fast)[5]	Beam phase monitor[6]	Momentum analyzer (future plan)	

Existing Linacs								
ISIS Linac	Wire scanners (low rep. rate only) in LEBT between preinjector and injector and in HEBT between injector and synchrotron[1]	Slit-and-collector in LEBT between preinjector and injector	Wire scanners (low rep. rate only) in LEBT between preinjector and injector and in HEBT between injector and synchrotron	Argon-filled ionisation chambers running alongside Tanks 2, 3, 4 and alongside HEBT beam line	Toroidal current transformers, three between preinjector and injector, three between tanks, five in HEBT	1. In HEBT straight before debuncher, fast toroids, time-of-flight measurement of beam bunches using 1 GHz 'scope 2. After debuncher, phase detection at 202.5 MHz on signals from capacitive pick-ups (see Note 2) 3. See Note 3	1. No energy spread measurement before debuncher 2a. After debuncher, by bending magnet and wire scanner (low rep. rate only) 2b. After debuncher, by monitoring time evolution of chopped beam in synchrotron	DT condition by monitoring X-ray dose rates from tanks[4]
INR (Moscow) Linac	Wire scanner, harp	Injection line - slit/collector, higher energies - rms with 3 to 5 wire scanners	Strip line, TM_{110} cavity[1]	Photomultiplier without scintillator, ionization chamber	Current transformer, wall current monitor for short pulses	Absolute and relative energy-time of flight with two current harmonic monitors, phase - current harmonic monitor	Magnnetic spectrometer/bunch shape monitor	Residual gas monitor[2], collector combined with energy degrador for phase scan
LANSCE Linac and transport lines	Wire Harp	Slit and collector[4] rms with multiple profiles[5]	Stripline w/ 50 ohm termination Capacitive (ring extraction line)	Ion Chamber[12] Liquid Scintillator	Toroid Faraday cups			Secondary emission current monitors Guard rings Absorber
LEDA Injector	Video using either viewscreens or background gas fluorescence	Off-line emittance measuring unit, measures part of r-r' space	None	None	Toroid (DC and AC)[7]	Power Supply potential		Potential on ring (Electron Trap) provides improved accuracy input

					arc current			
LEDA Halo Line	Wire scanner/Halo scraper[2]	rms fits from 4 profiles with~$\pi/2$ phase advance between profiles	Micro-stripline w/ 50 ohm termination[3]	Ion Chamber[5]	Toroid (AC)	Cylindrical Capacitive, 50 ohm termination[4]		
		rms from single profile scanning upstream magnet		CsI Scintillator[6]	Wall current	Resistive wall current		
LEDA HEBT	Wire scanner	rms from single profile scanning upstream magnet	Stripline w/ 50 ohm termination[3]	Ion Chamber	Toroid (AC)			Beam Stop Power
	Background gas fluorescence using injected nitrogen.[1]		Capacitive (ring, ring extraction line)	CsI Scintillator				
GSI Linac	Harp, IPM, fluoresence[1]	slit-grid, pepper-pot[2]	capacitive pick-up, 2 GHz bandwidth		Toroid (AC)[3]	capacitive pick-up[4]	particle-detector[5], bunch shape monitor[6]	
IPNS Linac								
Source and 750 kV column		slit scanner, test stand only		CT[1]	CT			
50 MeV Linac				CT, LM[2]	CT			
50 MeV Line	WS[3], Scintillator[4], SFC[5]	ESEM[6], WS[7]	terminated strip-lines	liquid scintillator/PMT, CT	CT	ESEM	ESEM	
CERN Linac		Slit & secondary emission grid[2]	Magnetic pick-ups	CT difference[1]	CT			
BNL Linac		Slit-collector, WS	striplines	scintillators	Toroid, Faraday cup, FCT	TOF (not used)		

Additional Notes:

SNS:

H- linac, 52 mA
DTL structure from 2.5 to 86 MeV,
CCL structure from 86 to 185 MeV
SC from 370 to 1 GeV (beta = 0.61 and 0.81 families)

1) A prototype will also be in the lower energy MEBT. Highly desirable for superconducting region to minimuze risk of particle contamination of cavities.
2) Transverse measurements. Temporary devices will be available during commissioning of lower energy MEBT and DTL systems
3) Longitudinal measurement.
4) Dual plane, 4 stripline design. position + relative phase ,402 + 805 MHz, direct IF digitizer @ 40 M Samples/sec
5) Volume detector (N) (~ 10 kHz,)
6) Photo multiplier, > 1 MHz response, MPS input.
7) Fast current transformer, 15-50 mA

RIA:

low energy:< 9.3 MeV/u, medium energy: < 80 MeV/u, high energy > 80 MeV/u
For the RIB Linac of RIA, diagnostics sensitive to beam intensities from 10^2 to 10^{11} particles per second are needed.
Secondary electron/position sensitive micro-channel plate detector, surface barrier detectors, gas counters for detecting individual ions will be important.
1) Superconducting Resonator used as Phase Monitor
2) RF deflection of secondary electrons
3)Solid State Diode Detector or Gas Counter to verify beam purity.
4) Low-duty factor operation for these diagnostics using a beam chopper..

FNAL P driver

400 MeV Line
1) Integrating over injection
2) B163Hz - 20 MHz, injection turn resolution, 0.1%

J-PARC (JKJ)

1) Fast response.
2) Measured in the MEBT at 3 MeV
3) Argon gas
4) Beam current range 0.1 - 100 mA

5) Frequency response: 20MHz - 3 GHz, rise time: 500 psec
6) Using fast toriods. Energy is measured by TOF in principle, detecting a phase difference between RF components of the signals from two fast toroids at separated positions.

ISIS:

ISIS linac is 70 MeV 202.5 MHz H^- injector for ISIS 800 MeV synchrotron
Four tanks: 665 keV input energy from Cockcroft-Walton preinjector – 10 MeV, 10 – 30 MeV, 30 – 50 MeV, 50 – 70 MeV
Debuncher cavity in HEBT between injector and synchrotron
At present linac runs with 20 mA pulses, ~200 μs long, at 50 pps
In 2003, RFQ (already running on test stand) will replace Cockcroft-Walton, and will lead to 30 mA pulses within linac

1) Two "beam diluters" (each essentially just a pepper pot lid) are provided in LEBT between preinjector and injector to attenuate beam to 40% or 10% (or 4%) while setting up
2) Useful for monitoring variation of energy during pulse
3) "Threshold foils", *viz* blocks of graphite which just stop 30, 50 and 70 MeV protons are provided shortly after the end of the linac for rough energy identification

4) Excessive X-ray dose rate is symptom of excessive electron emission from drift tube surfaces within tank. High numbers of electrons inside tank lead to charge being deposited in RF window at rate higher than charge can leak away, and lead to window breakdown

5) On RFQ test stand, input and output beam emittances measured using slit-and-collector devices, output beam energy spectrum measured using novel gas scattering spectrometer (and, shortly, using magnetic spectrometer), output beam bunch width measured using coaxial target

INR Linac

•Energy = 500 MeV
•Current 15 mA
•200 μs, 50 Hz
•Up to 150 μA average
1) Now out of use. Both monitors and electronics were designed and fabricated improperly.
2)Big noise due to emission from the accelerating cavities. Is planned to be installed in the injection line.

LANSCE:

1) Nitrogen at 1 std. atm. Same type of ion chambers also used in personnel protection system.
2) Used for fast, ns time scales. Saturates on PSR extraction losses.
3) Fast, but less sensitive, so does not saturate on PSR extraction losses.
4) Slit and collector method used up to 100 MeV.
5) Used at 800 MeV.
6) Primary BPM system for ring, but only works well for injected beam with 201 MHz structure.
7) Only have a couple of these in the ring.

8) No profile measurements in ring, but measure profile immediately after extraction. Can deduce ring profile at any time by extracting early.
9) Have both fast and slow toroids.
10) Used after each DTL tank.
11) ANL-style, with LANL-developed high-bandwidth electronics at detector
12) Also use ion chambers for personnel protection (separate electronics from loss monitors)

LEDA:

1.) Background gas or luminescent monitor tested and compared with traditional wire scanner. Reported in BIW2000.
2.) Integrated wire scanner with halo scraper, typical 100000:1 range, charge detection method, stepper motor actuation.
3.) Dual plane, 4 micro-stripline design. Position processor, 350-MHz, Log-ratio technique + on-line calibration, +/- 0.1 dB over >75 dB range, digitizer @ 1 M Sample/sec.
4.) Uses capacitive and resisive wall current monitors. < 0. 1s degrees at 350-MHz, 200+ kHz BW, > 45 dB dynamic range, full 2π measurment range.
5.) Standard volume detector. Operated from 10s kHz to few Hz.
6.) PM tube and CsI scintillator allowed for >10^7 dynamic range.
7.) DCCT from Bergoz with few 0.1 Hz to 100 Hz BW, ACCT from Bergoz with few Hz to near 1 MHz BW. Both capable of performing transmission measurements with range of few 0.1s mA to >100mA range.

IPNS

50 MeV H- linac
1) Pearson Coil and home-built, 100 mV/mA amplified, <20 MHz BW, full power
Radiation Monitors (ERMs)
3) Wire Scanners, horiz. and vert., low power, reduced bandwidth
4) plastic scintillator and video camera (reduced bunch, low power)
5) Segmented Faraday Cup (reduced bunch, low power)
6) Energy Spread and Energy Monitor, terminated BPMs (longitudinal, full power)
7) stepping and stationary wire (temporal macropulse, low power, low BW)

GSI Linac

all ions, up to 10 mA, pulse length 0.1 - 5 msec, frequency 36/108 MHz up to 18 MeV/u
1) Harp: dynamic shortening of pulse length, IPM: ion detection, no MCP, Fluoresence: equiped with Chevron MCP image intensifier
2) slit-grid: dynamic shortening of pulse length, pepper pot: Al_2O_3 viewing screen
3) GSI design, droop 0.5% for 5 ms, 0.1 microA resolution used for dynamic pulse shortening
4) using TOF, resolution > 1.e-4
5) attenuation by Rutherford scattering, used fast diamod and 50 Ohm MCP detectros, coincidence technique yield phase and energy of single particles
6) Uses secondary electrons from residual gas, prototype development

CERN Linac

1) Watchdog program monitors 2 consecutive pulses
2)Transverse and longitudinal emittances for single pulse

BNL Linac	H- beam •Energy = 200 MeV •Current 35mA •500 μs, 7.5 Hz •Up to 150 μA avg. for BLIP •Polarized proton 300 μA, 65% Polarization